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TO PROF. M. REDHEAD FAX N. 0044-1223-334554

FROM GC GHIRARDI

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**MESSAGE**

Please forward it to Prof. Redhead as soon as possible.

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Trieste december 6, 1995

Dear Michael,

I apologize for the delay but in this period my life is impossible for bureocratic and teaching duties and I am engaged from morning to evening.

I thank you for your remarks. To answer let me consider the two following statements and let me analyze various conceivable situations which might occur:

a) $OM - Loc \wedge \text{No conspiracy} \supset B - Loc$

b) $B - Loc \wedge \text{No conspiracy} \supset OM - Loc.$

Suppose we have two persons, Alice and Bob each of them tossing a coin every second.

1. Suppose OM-Loc holds, i.e. the two outcomes do not influence in any way each other. There still is the remote possibility that, in a very long sequence of experiments, due to accidental coincidences, the two outcomes turn out to be correlated. This means $\neg(B - Loc)$. This example shows that in order to claim that $OM - Loc \supset B - Loc$ you need to assume No conspiracy.

2. Suppose the same "experimental situation" occurs, but now assume explicitly that the two events influence each other, however in a quite peculiar way. It could happen, e.g., that in 1/2 of the cases the reciprocal influences lead to anticorrelated results (tail-head, head-tail) and in the remaining cases to perfectly correlated outcomes (tail-tail, head-head). [We have enriched here the simple example of our previous paper in which we were considering (with reference to spin variables) a complete reversal of outcomes when two coins are tossed with respect to the one in which one alone is tossed.] Since we have explicitly assumed that the outcomes influence each other we have $\neg(OM - Loc)$, but the probabilities satisfy $(B - Loc)$. Thus also $(B - Loc) \supset (OM - Loc)$ requires the No conspiracy assumption.

3. Our third case is more complex. Alice can choose whether to toss or not her coin, but we assume that the outcomes are independent, i.e., no influence from one event to the other can occur. In spite of this assumption it could happen, for an accidental conspiracy, that in all cases in which Alice has thrown a coin Bob has registered a tail. The conclusion would be $\neg$(P.I.) , so also your eq.(2) requires the No conspiracy assumption, to be correct.

4. The crucial point of the paper, as you appropriately stress is the relation

(OM – Loc) ∧ No conspiracy ⊃ O.I.

I would like to mention this very naive argument. If OM-Loc holds and nature is not cheating us, the probabilities of the various outcomes must factorize. On the other hand, if these probabilities do not factorize one would be led to claim that one outcome influences the other, but this is equivalent to ¬(OM – Loc).

5. I stress that, in my opinion, one could have No conspiracy, ¬(OM – Loc), ¬(O.I.) and (P.I.), and that this would by no means require that nature is cheating us. In fact, ¬(OM – Loc) would then emerges clearly from the existing correlations between outcomes even though P.I. holds.

6. I come now to your most relevant remark, i.e., why a violation of ER-Loc would be worse than a violation of OM-Loc? This is a good question which, however, has in our opinion a reasonable answer. To comment on this point let me go back to the case of deterministic hidden variable theories. Obviously people claim that in such a case they are in greater difficulty with relativity than in the case of. quantum mechanics because would one have access to the hidden variables one could:

a. Send faster than light signals

b. By the above trick produce a real contradiction by using backward causation effects of the type: consider three space-time points A, B, C such that B is space-like with respect to both A and C, while C is in the absolute past of A. Would one have access to the hidden variables there might be situations in which A could cause an effect at B and B might correspondingly make C aware of what A has done. Being C in the past of A he could forbid A to perform his original action.

In the present case one could imagine a similar situation (obviously one is simply contemplating logical not practical possibilities, just as one canno think of having a practical control of hidden variables). Thus, if you choose a position which allow you to assert that there is an instantaneous creation of an element of physical reality at-a-distance, you could also imagine that one could "in principle" be able to perceive this (actually E. Squires (Phys. Lett. A 163, 356 (1992)) in his paper criticizing (in a wrong way, see Phys. Lett. A 166, 435 (1992)) our relativistic models has contemplated the possibility that one could have access - through some sort of "classical" coupling - to the quantum mean values and thus to elements of physical reality. Therefore, if e.g., there would be a coupling with the mean value of the spin component it is obvious that by taking into account such a coupling one could detect the transition from the singlet to one of the reduced states since the mean value would change from 1/2 to 0 or 1 as a consequence of a far measurement). On the contrary, if you have only a violation of OM-Loc and it is due to a violation of O.I., then even the hypothetical superluminal signals would occur genuinely at random according to nature and they cannot, even in

principle, be considered as accessible to the experimenter (you do not have access to the alternative worlds).

Concluding on this point we believe that it is reasonable to consider that a violation of ER-Loc is more serious, from a relativistic point of view than a violation of OM-Loc. Actually, as we all know, the violation of OM-Loc through a violation of O.I. characterizing standard quantum mechanics implies only the conceptual possibility of signals or actions which are fundamentally out of the access of the observer and are run by nature itself. This shows that such effects, which we stress occur within standard quantum theory, cannot in any way be considered as a parameter dependence effect occurring case-by-case. We believe that this is the deep meaning of the analysis of Jarret.

I do not know whether you will consider our arguments of some value or not. I think that our discussion has been useful and I hope you will find in it the motivations to tell something on this (in our opinion) interesting problem.

Before concluding I would like to call your attention on an important fact. I think that, just as this fact has guided us in writing our original paper (which was conceived in the upside-down way with respect to the presentation we have given - i.e. we first had the model then we worked out the general proofs. Actually the model itself was a counterexample to the possibility of making the claim that there is a violation of ER-Loc) it could help you, who are much more expert than we are in these subtle matters, to consider seriously the following oversimplified example aiming to show that we cannot be wrong.

7. The way to reach our goal is that of building up an explicit consistent model in which there is:

$$\mathrm{ER-Loc},\ \neg(\mathrm{OM-Loc}),\ \text{(P.I.) and}\ \neg\text{(O.I.)}.$$

This is actually what, in a sense, we did in our original paper since we had a CSL model with many problems but whose conceptual structure satisfied the above requests. Obviously we had many technical difficulties because we were in search of a complete relativistic dynamical reduction model, accounting for all processes (in particular agreeing with quantum field theory).

But for our present purposes one can play the following game.

-Choose one reference frame and a space-like surface $\sigma_0$ on which you assign a statevector representing your initial conditions, and suppose they describe a pair of spin 1/2 particles with "practically well defined world lines" and in the singlet state.

- Identify two space time points L and R (the places where "apparatuses" are located along the world lines of the two particles).

- Leave at free choice whether the "apparatus" at L (R) is on or off and which label it carries. We will then have

(L-on **a**), (L-off **a**), (R-on **b**), (R-off **b**).

- Assign the evolution equation from $\sigma_0$ to an arbitrary space-like surface $\sigma$ which is in the future of $\sigma_0$, call $V(\sigma_0,\sigma)$ the space time volume between the two surfaces and use the following prescriptions:

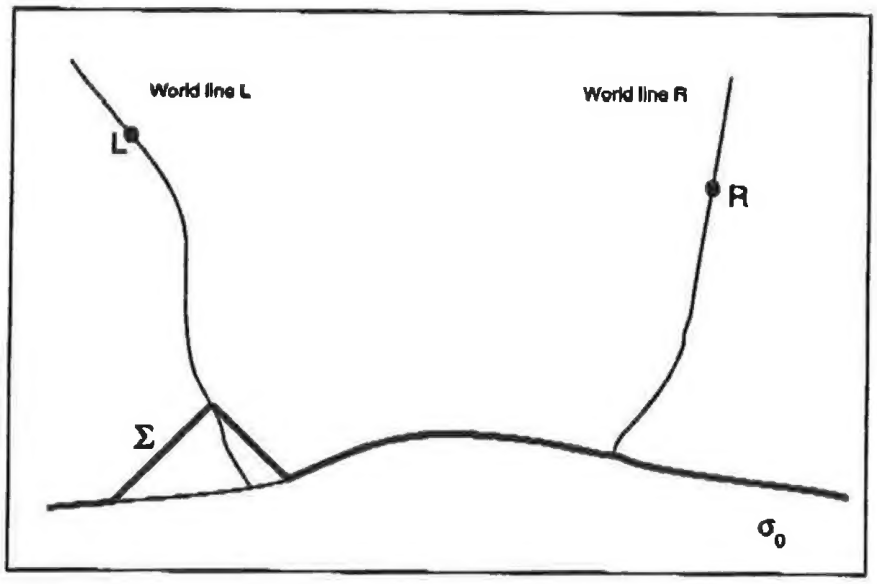
1. $|\Psi,\sigma>=|\Psi,\sigma_0>$ if neither L nor R belong to $V(\sigma_0,\sigma)$, or, in case one or both of them belong to $V(\sigma_0,\sigma)$, they are off.

2. $|\Psi,\sigma>=|a;+,->$ or $|a;-,+>$ if L belongs to $V(\sigma_0,\sigma)$ and L is on, while R either does not belong to $V(\sigma_0,\sigma)$ or it is off or both. The meaning of the two above states is obvious (the left particle has spin up + (spin down -) along **a** and the right one has the opposite orientation along the same direction). They occur with equal probability at random.

3. $|\Psi,\sigma>=|b;+,->$ or $|b;-,+>$ if R belongs to $V(\sigma_0,\sigma)$ and R is on, while L either does not belong to $V(\sigma_0,\sigma)$ or it is off or both. The meaning of the two above states is obvious. They occur with equal probability at random.

4. $|\Psi,\sigma>=|a,+;b,->$ or $|a,-;b,+>$ or $|a,+;b,+>$ or $|a,-;b,->$ with the appropriate probabilities if both R and L belong to $V(\sigma_0,\sigma)$ and are on.

5. A spin property is possessed by one of the two constituents at a certain point of its worldline iff the statevector on the surface $\Sigma$ (bold in the figure) obtained by drawing the past light cone from such a point back to the initial space-like surface and the part outside it of such a surface is an eigenstate of the corresponding spin observable (see the figure)




This model has all desired features: it does not have parameter dependence, it does not have istantaneous creation of elements of reality at-a-distance, it violates OM-Loc by exhibiting outcome dependence.

These are my reactions. I apologize for having probably been a little bit messy, but I wrote this in various small pieces. However I think that there are various points of discussion and I hope our exchanges of views will lead to an interesting outcome.

With my warm whishes

Giancarlo

PS. I am coming to London for few days. I have not yet my plan completely fixed but I will be probably there on saturday 9 and/or sunday 10 (on monday I am at the EJP editorial board meeting). Are you by any chance in London in those days? If yes we could manage to meet shortly or at least to speak by telephone. I cannot commit myself entirely to this because I have a flou and I hope it will not interfere with my travel.